

at all. The 2001 RAND analysis of MACDAR aircraft calculated an average cumulative quantity slope of 85% and rate slope of 95%. The rate slope was not statistically significant at the 90% or 95% confidence level. (Younossi, 2001)

MANUFACTURING MATERIALS

While limited research on the relationship between unit cost and production rate has been performed for the support labor functions, even less has been performed for manufacturing materials. The 1974 RAND analysis is the only study the author has found which addresses this subject at all.

By material, we mean raw and semifabricated material, small purchased parts (such as valves, electrical fittings and fasteners) and purchased equipment (batteries, actuators and instruments). It specifically excludes major avionics and subsystems, i.e., radar, communications / navigation, et al. It also excludes build-to-print structural parts. For such items, the impact of rate would be expected to fall along the same direct labor and indirect costs categories as discussed in this paper.

Materials are considered to have relatively flat improvement curves – the common range is 85% to 95%. Two major drivers are commonly identified. First, scrappage and material waste are reduced over time as manufacturing processes become more efficient. Second -- and more relevant to our subject -- suppliers generally provide cost discounts for sufficiently large quantities of materials. (Large, 1974) Conversely, at low production rates, companies may find minimum buy quantities requiring, for example, that certain fasteners can only be bought at a minimum quantity of, say, one thousand per order even though a lesser quantity is actually needed by the program.

Production rate might be expected to influence raw material unit cost by triggering larger quantity discounts from raw material and hardware suppliers. It is also suggested the higher production rates induce OEMs to offload more work to smaller manufacturers with low overheads and low costs.

However, benefit from higher production rates to improvement curve slopes is not apparent. An analysis of aircraft material learning curve slopes and production rates (as measured by the number of months required to accept the 100th aircraft) shows very little apparent impact. On the other hand, RAND did find a larger impact of production rate on the cost of raw materials, purchased parts, and purchased equipment on missile programs. (Large, 1974)

RAND notes the difficulty of analyzing material costs due to the need to adjust for inflationary impacts over time, arguing that these sometimes artificial adjustments introduce an additional element of uncertainty to the analysis. Similar to its conclusions on manufacturing, RAND concluded: "On the evidence it appears that in fact rate may have some effect, but a more detailed study would be required to determine why that should be true and how important that effect is." (Large, 1974) But in the subsequent 40 years, no one has taken up the call for such a study.

OVERHEAD / INDIRECT COSTS

Another area where there is little published research are indirect costs, such as overhead, general & administrative (G&A) costs, and cost of money. This is curious because indirect costs are generally the single largest component of cost. Indirect costs alone average 53% of contract costs in the defense industry. By contrast, less than 30% of product cost is touch labor or direct material. (Saha, 2002) Furthermore, at least some analysts believe overhead costs are leading contributors to the rate effect. (Dorsett, 1989)

For this paper, we will treat "overhead" and "indirect cost" as synonymous. By indirect costs, we mean costs which are necessary to the overall business operation, but at the same time do not show a direct relationship to any particular cost objective. Indirect costs are typically allocated to direct end-use

contracts on the basis of direct labor hours, direct material dollars, floor space or some other allocation bases. Direct costs, on the other hand, are costs incurred specifically for a contract.

Overhead is a mix of fixed, semi-fixed and variable costs. Examples of fixed costs would include depreciation, taxes, insurance, utilities, rents and professional services; semifixed costs would include data processing, allocation of corporate expenses, IRAD, B&P; variable costs would include indirect labor, machine maintenance, operating supplies, training expenses, and travel. (Large, 1974)

Indirect costs are of interest because of the sizable fixed element of costs. To the extent that costs are fixed, then increases or decreases in production rates will allocate those fixed costs over a larger or smaller base, inversely impacting unit cost. Having said as much, it is surprising so little published research has performed on overhead impacts. Unfortunately, the analyst faces multiple difficulties when analyzing overhead impacts:

1. Detailed data is typically unavailable. Industry jealously guards its indirect cost information over justifiable concerns of accidentally providing valuable cost information to its competitors. The information that is available is usually at a very high-level, making detail analysis impossible.
2. Companies have differing accounting practices with regard to the definition of direct and indirect cost. Certain functions, such as industrial engineering, may be a direct cost at Company A but an indirect cost at Company B. This makes cross-company comparisons difficult.
3. Accounting changes over time may move a given element from direct to indirect, or vice versa, over a period of time. Changes in accounting practices can complicate a time series analysis, or even invalidate it.

Nonetheless, there are at least two studies of the relationship between overhead cost and production rate. The first is a NAVAIR analysis of 15 aircraft manufacturers from 1975-1986 using data from the

Plant-Wide Data Reports (DD 1921-3) conducted by Thomas Gilbride. His analysis constructed macro-level overhead models for manufacturing, engineering, material and G&A. After conversion to constant year base dollars, percent changes in the business base were correlated to changes in overhead rates.

Gilbride found significant relationships between business base and overhead rates, to the effect:

- A 10 percent increase in business base drove:
 - a 3.5 percent decrease in manufacturing overhead rates,
 - a 1.7 percent decrease in engineering overhead rates,
 - a 5.8 percent decrease in material overhead rates, and
 - a 4.6 percent decrease in G&A rates.

- Similarly, a 10 percent decrease in business base drove:
 - a 4.9 percent increase in manufacturing overhead rates,
 - a 6.8 percent increase in engineering overhead rates,
 - a 8.4 percent increase in material overhead rates, and
 - a 10.5 percent increase in G&A rates. (Dorsett, 1989)

This inverse relationship between business base and overhead rates is consistent with the rate effect model, provided that we assume that changes in business base are, in turn, driven by changes in production rates.

The second study comes from the 1974 RAND study. In it, RAND obtained overhead data from five aerospace companies over varying periods from 1960 to 1972. Similar to the Gilbride study, RAND analyzed the relationship between percent changes in overhead rates related to percent changes in direct labor cost, after accounting for inflationary impacts. RAND concluded that a 4 percent increase in direct labor caused a 1 percent decrease in the overhead rate, and vice versa.

In a secondary analysis, RAND examined overhead cost as a function of total recurring cost for a sample of 45 production lots of aircraft over the 1953-1972 time period. The results showed that the ratio of overhead cost to total cost decreased when total cost increased -- a confirmation of its earlier

conclusion on the relationship between the movement of overhead costs to changes in business base.

(Large, 1974)

In its conclusion, RAND emphasized the chain of causality that ultimately drives indirect costs. “While it may seem a fine distinction, we cannot say that production rate per se affects overhead costs. Rate affects volume of business, and the effect of volume on overhead can be appreciable.” (Large, 1974)

CONCLUSION

What can we conclude from all this?

Exhibit 9 below summarizes the impact of production rate on unit costs by functional area and identifies if the changes in production rates are positively or negatively correlated with unit cost and apparent strength of that relationship. For example, in the long term, changes in production rate are inversely correlated with manufacturing labor hours (i.e., an increase in production rate decreases manufacturing hours per unit) but only weakly. On the other hand, changes in production rates are strongly and inversely correlated with overhead costs. Interestingly, it appears any significant change in production rate – either an increase or a decrease – adversely impacts manufacturing unit costs, at least in the short run. When it comes to total weapon system cost – the summation of all of these functional cost categories – there appears a moderate to weak correlation between production rate and unit cost. Because of the statistical uncertainty surrounding much of the published analysis, however, it is difficult to generalize on the magnitude.

Exhibit 9.

Functional Area	Impact of Production Rate on Unit Cost			
	Strong	Moderate	Weak	None or Uncertain
Manufacturing (Short-Term)	Increase in hours for rate changes, positive or negative			
Manufacturing (Long-Term)			Inversely correlated	
Tooling (Rate)	Positively correlated			
Tooling (Sustaining)		Inversely correlated		
Engineering (Non-Recurring)				None apparent
Engineering (Sustaining)		Inversely correlated		
Quality Assurance				Insufficient evidence
Materials			Inversely correlated	
Overhead / Indirect	Inversely correlated			
Total Weapon System		Inversely correlated		

Three salient facts stand out about the published evidence.

First, there is a significant area of grey around these conclusions. Different authors have come to contradictory conclusions – sometimes looking at the same basic data! – and most studies have suffered from an inability to tease strong conclusions from highly collinear data.

Second, outside of manufacturing, there are a number of functional areas where only one or two studies have been performed. The areas of support labor, overhead and materials are seriously

underrepresented in terms of the number and depth of studies examining the relationship of unit cost to production rate (indeed, on the broader subject of cost improvement in general). This cries out for future research to re-examine these neglected areas.

Third, the astute reader will note that most of these studies were performed during the late 1960's through the 1980's. Since then there has been very limited amount of new research published on the subject. Clearly we cannot say the issue has been settled, although some cost analysts have pushed ahead on the brave assumption that there is a proven relationship which can be incorporated into cost estimates. Perhaps the subject has fallen out of favor; or perhaps there is only limited new data to analyze – after all, the quantity of new DoD hardware programs to analyze has dropped substantially since the Reagan era. But this question is not limited to Defense Department hardware; indeed, many rich examples should exist outside the defense industry, and perhaps it is time to try and mine this vein of data.

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Biography

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